The Research on Erosive Destruction of Sliding Sleeve of Cementing in Horizontal Wells

GuoJing Guo, SongTao Jiu, XiaoHua Li

***Abstract*— In order to research the wear pattern and reliability of the cementing sliding sleeve under the circumstance of high sand ratio and large flow, this article utilizes the Dense Discrete Phase Model(DDPM) to forecast the internal particle movement and distribution regularities of the cementing sliding sleeve; uses the erosive model given by Tulsa University to solve the erosion rate of the particle to the cementing sliding sleeve; designs related tests; analyzes the correlation between erosion rate and the quantity of the perforation under the circumstance of less change of sand ratio and flow and verifies the validity of the prediction model to the numerical modeling. The result indicates that numerical modeling can forecast the erosive location of the cementing sliding sleeve correctly and receive the quality loss through unit integral erosion rate. The tests differences from 14.03%, 10.15% and 6.46% explain that the numerical modeling can take well advantage of the cementing sliding sleeve erosive modeling under the high sand ratio. This article analyses the movement characteristics of the internal flow field and particle; explains the reasons of erosive destruction; applies the further optimized reference to cementing sliding sleeve.**

***Index Terms*—Cementing Sliding Sleeve, Erosion Research, Staged Fracturing, Numerical Modeling**

I. INTRODUCTION

Casing cementing sliding sleeve staged fracturing is a new reservoir stimulation technology, which mainly used in unconventional oil and gas fracturing simulations , the process principle is: according to reservoir reconstruction needs, put a plurality of sliding sleeves along the bushing down into the well at at once after the implementation of the conventional cementing, through open sliding sleeve in a particular manner step by step to fracturing layer by layer, thereby increasing the output of oil and gas wells. The technology has the features like unlimited construction fracturing stages, full bore within the column, no drilling job, in favor of the latter part of the liquid flow back and subsequent tool setting ,and high reliability construction; can significantly improve the fracture rate, shorten construction period and increase operational efficiency[1-3].

With the large-scale exploration and development of unconventional oil and gas resources, horizontal well staged fracturing technology has been widely used. Casing cementing sliding sleeve, which serve as one of the key tools of staged fracturing simulations supporting, faces a serious erosion with the working environment which contacts with the fracturing fluid directly[4]. Erosion generally refers to the impact of fluid or solid particles with a certain speed and angle to the object surface, resulting in material loss. Erosion often occurs in the energy, machinery, chemicals, metallurgy, aerospace and other industrial sectors with more and more people's attention, erosion is now considered to be one of the important causes of equipment failure or material damage [5-6]. So the study of erosion characteristics of cementing sliding sleeve becomes increasingly important.

This paper use DDPM (Dense Discrete Phase Model) model[7] and the erosion model[8] that put forward by Tulsa University to study the internal flow field of cementing fliding sleeve, predicts the solid particle trajectory and mass loss during the erosion process ,provides some references for further study of cementing fliding sleeve erosion damage.

II. CALCULATION MODEL

1) flow field model

Flow field calculation can use a non-steady state continuous equations and N-S equation theoretically, but in most cases, direct numerical calculation of time and space are far beyond the breadth of computing power. The most commonly used way to solve this problem is to use the Reynolds averaging method to simulate the turbulent flow whose effect was well proved by engineering practice. The k-ε model, with the small calculate volume, strong economy and high precision, is the most widely used eddy viscosity model , it is formated by the turbulent dissipation in rate ε based on the turbulent kine tic energy k equation[9]. For fracturing fluid Takasago ratio is a high Reynolds number turbulence, using the standard k-ε model is reasonable.

2) Particle tracking model

The present study of solid particle erosion is using more DPM model, which ignores the interaction between the particles, applies to the discrete phase volume fraction that is less than 10% -12% of cases; while the casing cementing sliding sleeve in staged fracturing process, due to the fracturing fluid displacement and high solid particle content, so the use of Dense discrete phase model (DDPM), which taking inter-particle collision and friction into account, applies to the discrete phase volume is larger (greater than 10 % -12%) and adapts to calculate higher sand particles fluidized system which the inter phase drag force takes a dominant role. The mass conservation equation and momentum conservation equation of DPM model[10] are respectively:

$$\frac{\partial}{\partial t}\left(\alpha_{\mathrm{p}}\rho_{\mathrm{p}}\right)+\nabla\cdot\left(\alpha_{\mathrm{p}}\rho_{\mathrm{p}}\,\mathbf{u}_{\mathrm{p}}\right)=\sum_{n=1}^{\mathrm{nphase}}\left(\dot{\mathrm{m}}_{\mathrm{qp}}-\dot{\mathrm{m}}_{\mathrm{pq}}\right) \quad (1)$$

$$\frac{\partial}{\partial t}\left(\alpha_{\mathrm{p}}\rho_{\mathrm{p}}\mathbf{u}_{\mathrm{p}}\right)+\nabla\cdot\left(\alpha_{\mathrm{p}}\rho_{\mathrm{p}}\mathbf{u}_{\mathrm{p}}\mathbf{u}_{\mathrm{q}}\right)=$$
$$-\alpha_{\mathrm{p}}\nabla p+\nabla\cdot\left[\alpha_{\mathrm{p}}\mu_{\mathrm{p}}\left(\nabla\mathbf{u}_{\mathrm{p}}+\nabla\mathbf{u}_{\mathrm{p}}^{\mathrm{T}}\right)\right]+\alpha_{\mathrm{p}}\rho_{\mathrm{p}}\mathbf{g}+\sum_{\mathrm{q}}k_{\mathrm{pq}}(\mathbf{u}_{\mathrm{q}}-\mathbf{u}_{\mathrm{p}})+\mathrm{S}_{\mathrm{other}} \quad (2)$$

α_p is volume fraction of solid particles; ρ_p is solid particle density ; $\mathbf{u}_q$ is solid particle velocity vector ; $\mathbf{u}_p$ is liquid

velocity vecto$_r$; μ_p is liquid viscosity ; **g** is gravitational acceleration vector ; m_{qp} is the mass liquid transfer to solid particle ; m_{pq} is the mass solid particle transfer to liquid ; k_{pq} is momentum conversion factor between solid particle and liquid ; S_{other} is consider of particle forces and virtual mass force .

Based on the DPM model ,Formula (1) and (2) considerate the inter phase mass transfer and momentum transfer, and can analog the particle size can be more reasonable than the analog the interaction between high sand ratio particles and the particle size distribution of particle phase.

3) Erosion equation

Erosion is a very complex process, influenced by solid particle velocity, particle impact angle, the target material properties, the properties of solid particles and fluid motion characteristics and many other parameters. Meng et[11] summarizes dozens of the mathematical models to be presented for the study of erosion , involving hundreds of variable parameters, the relationship between the parameters of the complex, and can not be expressed in a unified form. Among the most widely used equations include Finnie erosion cutting wear equation[12], deformation and cutting equation Bitter[13] and erosion model of Tulsa University. This article uses the erosion model proposed by the University of Tulsa, this equation considering the influence of solid particle impact velocity, impact angle, wall material hardness and solid particle shape and other factors on the erosion. The formulas are:

$$E_R = C(HB)^{-0.59} F_P V_P^n f(\theta) \quad (3)$$

$$P_R = E_R \cdot m_p / \rho / A_c \quad (4)$$

$$f(\theta) = a\theta^2 + b\theta ....(\theta < \theta_0) \quad (5)$$

$$f(\theta) = x\cos^2\theta(\omega\theta) + y\sin^2\theta + z..(\theta > \theta_0) \quad (6)$$

E_R is the wear rate of the wall material , kg/kg ; C is wall material constants ; HB is brinell hardness of the wall material , N/mm2; F_P is form factor of the solid particles , for the more sharper particles, semi-circular particles and particles , the date is 1、0.53、0.2 ; n is speed index ; V_P is impact velocity of solid particles , m/s ; f(θ)is impact angle function ; P_R is wall material erosion rate , m/s ; m_P is mass flow rate of solid particles , kg/s ; ρ is density of the wall material , kg/m3;Ac is area calculation unit , m^2 ; θ is solid particles impact angle ; θ_0、a、b、w、x、y、z are the empirical constants according to the wall material.

III. Cases Operators

1) Physical Model

Using a three-dimensional drawing software to draw a three-dimensional of the cementing sliding sleeve, as shown below, the sleeve inner diameter is 121mm, total length of sleeve is 950mm, aperture size is 90mm × 40mm, each respectively modeling use the fracturing perforations of 2,3,4 and symmetrical perforations distribution.

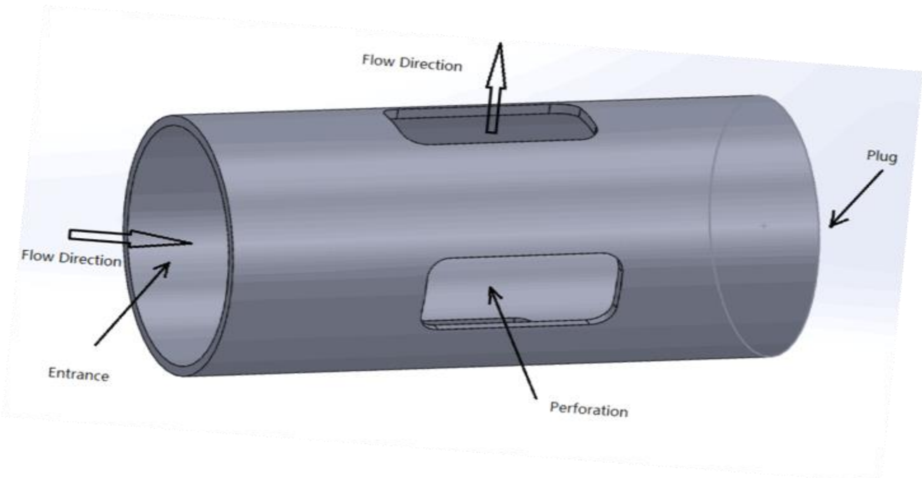

Fig 1 The cementing sliding sleeve

2) The numerical calculation method

Using the Fluent software to simulate, the k-ε model for continuous phase, DDPM to track solid particle .The continuous phase is water, the density is 998.2kg / m3, the dynamic viscosity is 1.003 × 10^{-3}kg / (m·s); the solid particles are sand, the average diameter is 0.6mm, a density is 1700kg / m3; The inner tube fluid is incompressible turbulent flow, the import using velocity boundary condition, outlet using pressure outlet boundary conditions[14];Using SIMPlE algorithm to process coupled speed and pressure, using the momentum of the first-order upwind scheme, the discrete turbulent kinetic energy and turbulent dissipation rate of second-order upwind scheme[15]; Selecting the residual changing rate ,which is less than 10-5 and the kinetic energy and momentum are between 2 adjacent iteration, as convergence condition. Cementing sliding sleeve material is 35CrMo alloy structural steel, are shown in Table 1.

Table 1The analysis result of the chemical composition of the material

Composition	Provisions content	Experimental value
C	0.32-0.40	0. 41
Si	0.17-0.37	0.25
Mn	0.40-0.70	0.66
P	≤0.035	0.02
S	≤0.035	0.01
Cr	0.80-1.10	0.93
Mo	0.15-0.25	0.20
Cu	≤0.030	0.02

3) Experimental verification

To verify the reliability of the simulation analysis, experimental scheme shown in Figure 2 is designed . Using double pump series and then in parallel with four-pump system as cycle power, extracting sand water flowmeter , pressure gauges 1, cementing sliding sleeve, pressure gauge 2, sampling valves from mixing pool then back to it., Wherein, in order to prevent the influence of the four corners' grit to the sand content in the stirring pool, the stirring pool uses four outlet design and uses the samples from sampling valves to monitor the liquid sand ratio. To prove the experimental validation through simulation analysis under the same parameters.

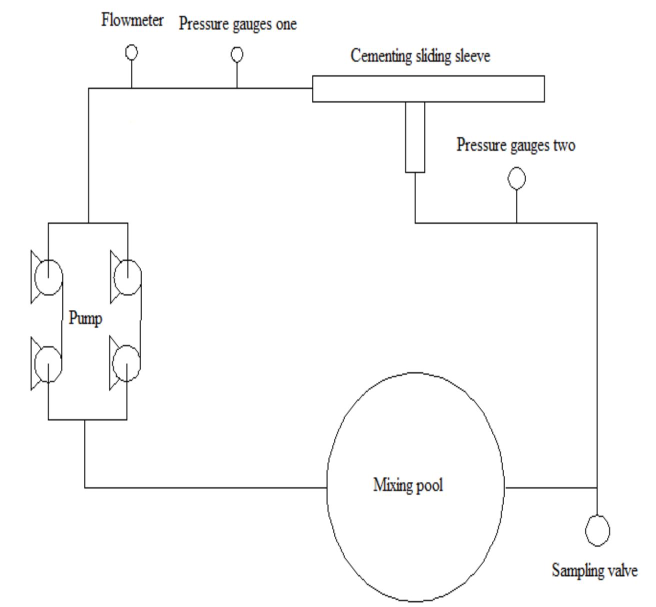

Fig2 Cementing sliding sleeve erosion testing procedures

IV. RESULT ANALYSIS

1) Erosion features comparison Conducting three four hours cementing sliding sleeve erosion experiments with 2,3,4 perforations respectively, and measure the experimental results. The measurement results are shown in the following table.

Table 2 Cementing sliding sleeve erosion results date

Number of perforation	Displacement (m^3/min)	Sand ratio%	Aperture length Maximum wear mm	Aperture width Maximum wear mm	Accumulated Loss/g	average erosion rate g/h
2	5.8	24.0	7.6	0.2	203	50.75
3	6.3	23.8	1.8	0	26	6.50
4	6.1	24.1	1.3	0	19	5.73

Fig3 The surface morphology before the cementing sleeve eyelet erosion

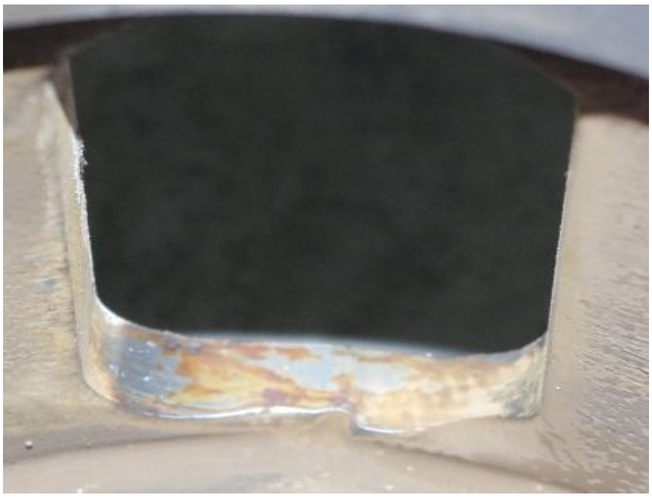

Fig4 The surface morphology after the cementing sleeve eyelet erosion

From the above table it can be seen in four hours erosion experiment, the length of three groups of sliding sleeve perforations has changed, which is respectively 7.6mm, 1.8mm, 1.3mm, the circumferential width of three groups sliding sleeve substantially has no change, only the group with two perforations increased 0.2mm, the accumulate loss of three groups is respectively 203g, 26g, 19g, the average erosion rate is 50.75g / h, 6.50g / h, 5.73g / h. Thus it can be seen, with the less change of displacement and sand ratio, the average erosion rate is inversely associated with the number of perforation. The surface morphology after the sleeve eyelet erosion is as shown, erosion occurs mainly in parts where the perforations face the fracturing fluid erosion directly, the site appeared very obvious signs of erosion damage.

Compare the experimental results and the theoretical results, the results are as shown:

Number of perforation	Experimental average erosion rate g/h	Theoretical average erosion rate g/h	Error %
2	50.75	43.63	14.03
3	6.50	5.84	10.15
4	5.73	5.36	6.46

By comparison, the errors between experimental average erosion rate and theoretical average erosion of the three groups tests with 2,3,4 perforations is respectively 14.03%, 10.15% and 6.46% , the error occurs mainly because the simulation ignores the sleeve eroding parts of shape changes in real time and some other variables caused.

2) Flow Field Analysis

3 perforations of the sleeve, for example, by using the simulation software Fluent , the nephogram of the inner fluid speed of the sliding sleeve and the trajectories nephogram of the solid phase particle can be seen.

From the the nephogram of the inner fluid speed we can see that the fluid flow rate at inlet portion in the sleeve is relatively stable, and increased rapidly to 22.6m/s when it went through the sleeve perforation due to the limiting function of the sleeve. The interaction between the sleeve and fluid in this region is larger than other regions ,and the cutting impact on the direction of the fluid sleeve positive is even larger ;after passing through the sleeve plug part into the annulus , the fluid speed is smaller.

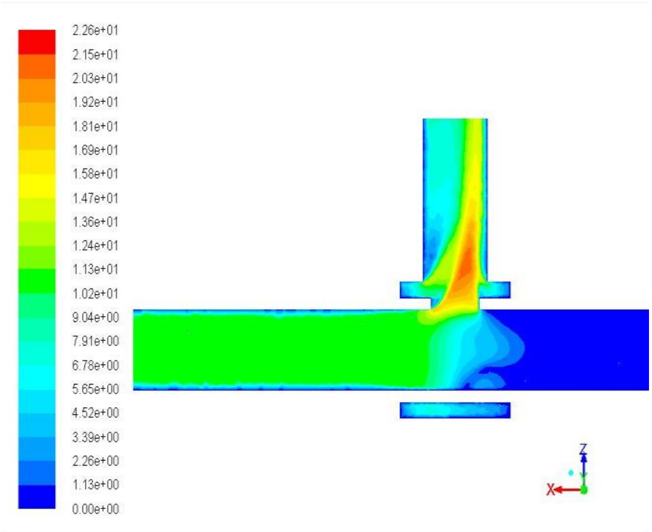

Fig5 The the nephogram of the inner fluid speed

The trajectories nephogram of the solid phase particle reflects changes in particle motion during physical variables. The particle speed tracking diagram(Diagram7) shows that the liquid carrying the solid move forward from the inlet, part of the particles run out through the annulus after scouring the liquid shock position directly, which is also the worst erosive position, part of the particles swirl in the area on the side near the plug and maneuver in the plug.

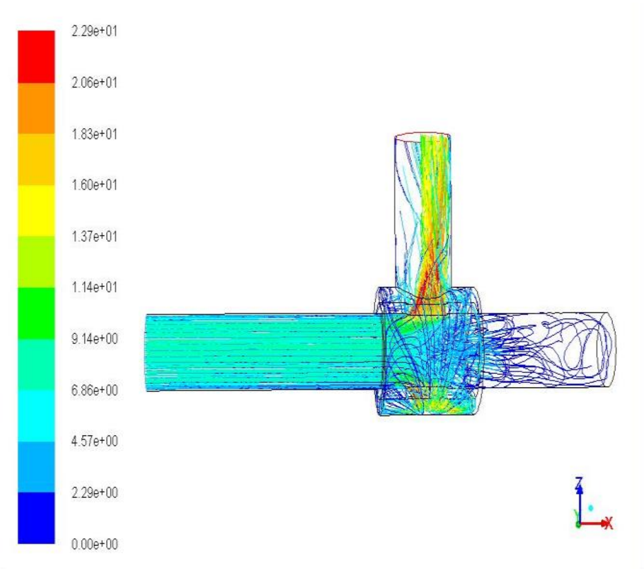

Fig6 The particle speed tracking diagram

Conclusions

(1)With the experimental analysis of cementing sliding sleeve erosion wear, it proves through experiments and simulations that the position of the selected model for erosion prediction has higher correctness.

(2)By comparing the simulations and experimental erosion rate, the error of the sliding sleeve with 2,3,4 perforations is 14.03%、10.15%、6.46%. The errors are mainly because of ignoring the real-time changes in the shape of the sleeve eroding position and the influence of other factors .

(3)The speed direction changes of solid particles occurs at the perforation, the sharp increase in the flow rate, the badly shock of the plug side near the perforation are the main cause of erosion damage to the sliding sleeve.

(4)Further research on the optimization of cementing sliding sleeve materials and structure is recommended to avoid the failure of parts occurs during the operation of the sliding sleeve.

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